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Statewide Greenhouse Gas Emissions Level: 1990 Baseline and 2020 Business As Usual Projection Update

Regulatory Authority:
MGL Chapter 21N, Section 3

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[1] These Appendices can be found at the following web page: http://www.mass.gov/eea/agencies/massdep/climate-energy/climate/ghg/greenhouse-gas-ghg-emissions-in-massachusetts.html

Introduction

The Massachusetts Global Warming Solutions Act (GWSA)[2] was signed into law in August of 2008. The major requirements of this statute include:

- Adoption of statewide greenhouse gas (GHG) emissions limits for 2020, 2030, and 2040 that will maximize the ability of the Commonwealth to meet the 2050 limit of at least 80% below 1990 emissions,
- Implementation of plans to achieve these statewide GHG emissions limits, and
- Mandatory reporting of GHG emissions by larger GHG emitting sources and retail sellers of electricity in the Commonwealth.

GHGs accumulate in the atmosphere and trap heat that would otherwise be radiated back into space. This "greenhouse effect" is the primary cause of global climate change. There are a number of gases that are considered GHGs. The most prevalent GHG is carbon dioxide (CO_2), which is emitted when fuels are burned. Methane (CH_4), nitrous oxide (N_2O) and several other compounds primarily used as refrigerants are also GHGs of concern due to their potential to contribute to climate change.[3]

GWSA established the Climate Protection and Green Economy Act in Massachusetts General Law, which requires the Massachusetts Department of Environmental Protection (MassDEP) to, among other actions "*… triennially publish a state greenhouse gas emissions inventory that includes comprehensive estimates of the quantity of greenhouse gas emissions in the commonwealth for the last 3 years in which the data is available,*" and "*…determine the statewide greenhouse gas emissions level in calendar year 1990 and reasonably project what the emissions lever will be in calendar year 2020 if no measures are imposed to lower emissions other than those formally adopted and implemented as of January 1, 2009.*" [MGL chapter 21N, section 2, subsection (c) and section 3, subsection (a)]

GWSA section 14 further required MassDEP to establish the 1990 Baseline and 2020 Business as Usual (BAU) Projection by July 1, 2009. The 1990 Baseline and BAU Projection were published July 1, 2009 and presented actual emissions from 1990 through 2008 for most sectors, and projected emissions to 2020 for all sectors.

GWSA required the Secretary of the Executive Office of Energy and Environmental Affairs (EEA), in consultation with other state agencies and the public, to establish a statewide limit on GHG emissions of between 10 percent and 25 percent below 1990 levels for 2020 — on the way to an 80 percent reduction in emissions by 2050 — along with a plan to achieve the 2020 limit [MGL chapter 21N, section 4, subsections (a-g)]. In December 2010, EEA set the 2020 limit at 25 percent below the 1990 Baseline level. The *Massachusetts Clean Energy and Climate Plan*

[2] See http://www.malegislature.gov/Laws/SessionLaws/Acts/2008/Chapter298

[3] Not all GHGs have the same heat-trapping capacity. For example, one ton of methane is equivalent to greater than 20 tons of CO_2 with respect to their heat trapping potentials. To account for these differences, a standard, known as the global warming potential (GWP), relating the heat trapping potential of each GHG to an equivalent quantity of CO_2 over a given time horizon, has been developed. Emissions shown in this document utilize this standard, and are expressed in units of million metric tons of carbon dioxide equivalents ($MMTCO_2e$).

for 2020 (2020 CECP), also published in December 2010, contains strategies to meet that limit.[4] The 1990 emissions baseline is the emissions level against which Massachusetts' future GHG emissions reductions limits will be planned and measured.

Updating the 1990 Baseline and the 2020 BAU Projection

The *Statewide Greenhouse Gas Emissions Level: 1990 Baseline and 2020 Business as Usual Projection* (July 1, 2009)[5] states: "The Department recognizes that the science and practice of determining GHG emissions is changing rapidly and that Massachusetts, being at the cutting edge of this work, should avail itself of advancements in the science to the extent possible. Therefore, MassDEP will reevaluate the 1990 Baseline as needed (e.g., significant new data becomes available). If amendment is necessary, a full public review process will be used."

Significant new data have become available, including revisions to the Global Warming Potentials (GWPs) of GHGs. The original 1990 Baseline/2020 BAU Projection and all MassDEP GHG inventories published to date are based on GWPs published by the Intergovernmental Panel on Climate Change (IPCC) in its Second Assessment Report (SAR) in 1996. This draft inventory and baseline update uses the two most recent sets of GWP values published by the IPCC, the Fourth Assessment Report (AR4) in 2007 and the Fifth Assessment Report (AR5) in 2013. The Department is seeking comment on whether AR4 or AR5 GWPs should be used when this updated 1990 Baseline/2020 BAU Projection is finalized (see section 5 of Appendix A of this document for a discussion of AR4 versus AR5). AR4 could be an appropriate choice because all national inventories are being updated to AR4. AR5 could be an appropriate choice as it incorporates the latest science, but would mean Massachusetts' GHG inventory would not be directly comparable to GHG inventories of other jurisdictions. In addition, the Department seeks comment on any of the methodologies and data described in Appendix A that were used to estimate Massachusetts' 1990 GHG emissions.

This draft 1990 Baseline/2020 BAU Projection update is open for public comment, ending December 23, 2015. Please direct any comments to climate.strategies@state.ma.us or Sue Ann Richardson, MassDEP, One Winter Street, 6th Floor, Boston, MA 02108.

GWSA requires the Secretary of EEA to update the CECP at least once every five years [MGL chapter 21N, section 4, subsection (h)] with the first 5-year update due by December 31, 2015. This updated 1990 Baseline inventory will support that 2020 CECP update.

- Part 1 of this document describes the update to the 1990 Baseline;
- Part 2 describes the updated Massachusetts 2020 BAU Projection;
- Part 3 is a comparison of the previous and updated GHG emissions; and
- Appendix A describes the updated sources of GHG emissions, data sources, and methodologies used to determine the updated Massachusetts 1990 Baseline and the 2020 BAU Projection.

[4] http://www.mass.gov/eea/waste-mgnt-recycling/air-quality/climate-change-adaptation/mass-clean-energy-and-climate-plan.html

[5] http://www.mass.gov/eea/agencies/massdep/climate-energy/climate/ghg/greenhouse-gas-ghg-emissions-in-massachusetts.html#2

Part 1: Massachusetts 1990 GHG Emissions Baseline Update

What is the purpose of the 1990 Baseline? GWSA calls for the Commonwealth to adopt GHG emissions limits for 2020, 2030, 2040, and 2050 expressed in terms of percent reductions relative to emissions in the year 1990. The emissions baseline presented here will provide an updated emissions level against which these future limits will be set and against which progress in achieving reductions will be measured.

Using the revised and updated data sources and methodologies described in Appendix A, MassDEP estimates that economy-wide GHG emissions in 1990 were 94.5 million metric tons of carbon dioxide equivalents (MMTCO$_2$e) with AR4 GWPs, and 94.9 MMTCO$_2$e with AR5 GWPs.

Table 1 below shows a breakdown of the updated 1990 Baseline GHG emissions by economic sector calculated using the AR4 and AR5 GWPs. The spreadsheets in Appendices C and D contain the calculations upon which the tables in Parts 1 and 3 and the figures in Part 2 are based.

Table 1: 1990 Baseline Update (MMTCO$_2$e)

	AR4 1990	AR5 1990
Energy Total	**90.6**	**90.7**
CO$_2$e from Fossil Fuel Combustion	88.1	88.0
Residential CO$_2$e from Fuel Combustion	15.3	15.3
Residential CO$_2$	15.1	15.1
Residential Other Gases (CH$_4$ & N$_2$O)	0.2	0.2
Commercial CO$_2$e from Fuel Combustion	8.4	8.4
Commercial CO$_2$	8.4	8.4
Commercial Other Gases (CH$_4$ & N$_2$O)	0.1	0.1
Industrial CO$_2$e from Fuel Combustion	5.7	5.7
Industrial CO$_2$	5.6	5.6
Industrial Other Gases (CH$_4$ & N$_2$O)	0.02	0.02
Industrial from Waste (CO$_2$, CH$_4$ & N$_2$O)	0.1	0.1
Transportation CO$_2$e from Fuel Combustion	30.5	30.4
Transportation CO$_2$	28.9	28.9
Transportation Other Gases (CH$_4$ & N$_2$O)	1.6	1.5
Electricity Total CO$_2$e from Fuel Combustion	28.2	28.1
Electric Generation CO$_2$	25.1	25.1
Electric Generation Other Gases (CH$_4$ & N$_2$O)	0.1	0.1
Electric Generation from Waste (CO$_2$, CH$_4$ & N$_2$O)	1.1	1.1

Electricity Imports (CO_2, CH_4 & N_2O)	1.9	1.8
Natural Gas Systems (CH_4)	2.4	2.7
Industrial Processes	**0.7**	**0.7**
Agriculture	**0.3**	**0.3**
Waste	**2.8**	**3.2**
Gross Emissions	**94.5**	**94.9**

Note: due to rounding to 1 decimal place, some totals appear higher or lower than the simple sum of the sectors.

Part 2: Massachusetts 2020 Business as Usual (BAU) GHG Emissions Projection Update

What is the purpose of the 2020 BAU Projection? This projection allows MassDEP and stakeholders to illustrate the magnitude of GHG reductions necessary to achieve the limit set for 2020 (25% below the 1990 Baseline). It provides a context to understand the emissions reductions achieved by implementing measures to reduce GHGs compared to what emissions would be if such measures were not implemented, i.e., Business As Usual.

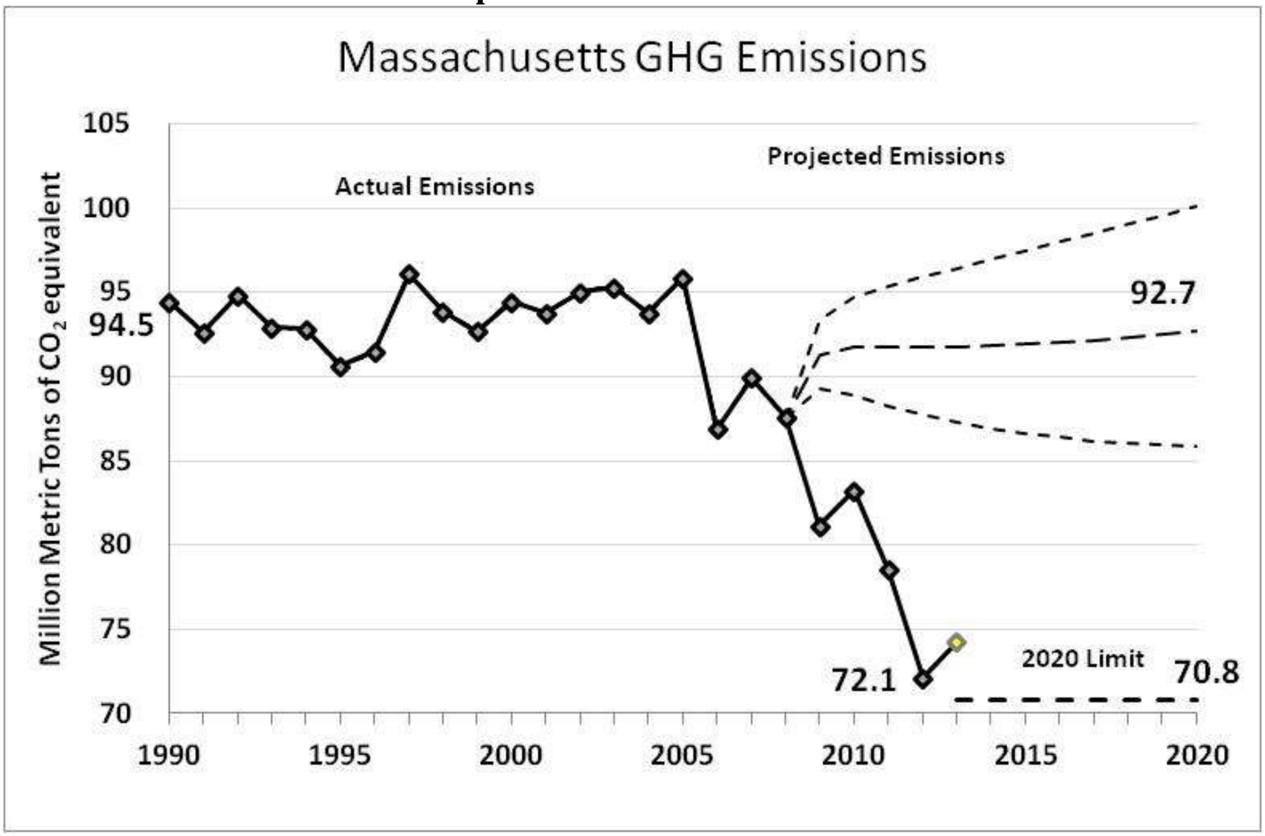
The updated 2020 BAU Projection has been developed using the same approach as the original 2020 BAU Projection published in 2009, by extrapolating from historical emissions trends. The updated 2020 BAU Projection shown in Figure 1, using the AR4 GWPs, results in 2020 BAU emissions of 92.7 $MMTCO_2e$.[6] The projection is labeled Projected Emissions and is represented as the heavy dashed line on Figure 1. This projection is based on a straightforward extrapolation of historical data rather than on a complex model that attempts to predict what the future holds. This updated 2020 BAU projection extends from 2008 out to 2020 as required by MGL chapter 21N, section 3, subsection (a). However, for this update, the data set from which the extrapolation is made is complete from 1990 through 2008 (which was not the case with the original projection published in 2009, when a complete data set was not available for all sectors).

Also shown on Figure 1, the lightly dashed lines reflect a reasonable range of uncertainty in emissions given the variability inherent in GHG drivers such as economic activity and fuel prices. As in the original 2020 BAU Projection published in 2009, these ranges are based on historical variability (50% confidence that expected emissions lie between the two lightly dashed lines) rather than on an analysis of factors that might drive emissions higher or lower than the historical trend line, and by how much.

Lastly, actual historical emissions are shown on Figure 1 through 2012. 2013 GHG emissions were higher than in 2012, but complete data are not yet available for 2013, thus 2013 is displayed as a lighter data point in Figure 1.

[6] For simplicity, the figures in this document present emissions using AR4 GWPs, but the corresponding figures using AR5 GWPs are available in the spreadsheets that accompany this document (Appendix C for AR4 and Appendix D for AR5).

Figure 1: Updated Massachusetts Baseline and Business as Usual (BAU) Projection of GHG emissions 1990-2020 based on AR4 GWPs, with historical emissions for 1990-2012 and partial emissions for 2013



Figures 2A and 2B provide a breakdown of the updated 1990 Baseline and 2020 BAU Projection by major sector. The figures demonstrate how the sectors comprising the overall Massachusetts inventory may be projected to 2020. All sectors have been projected from 2008. Actual historical emissions are also shown for each sector through 2012, with most, but not all, sectors having complete data through 2013. Other caveats noted above, along with the caveats about data quality in Appendix A, apply to each sector.

Figure 2A: Updated Massachusetts Baseline and BAU Projection of Fuel Combustion GHG Emissions 1990-2020 by sector based on AR4 GWPs

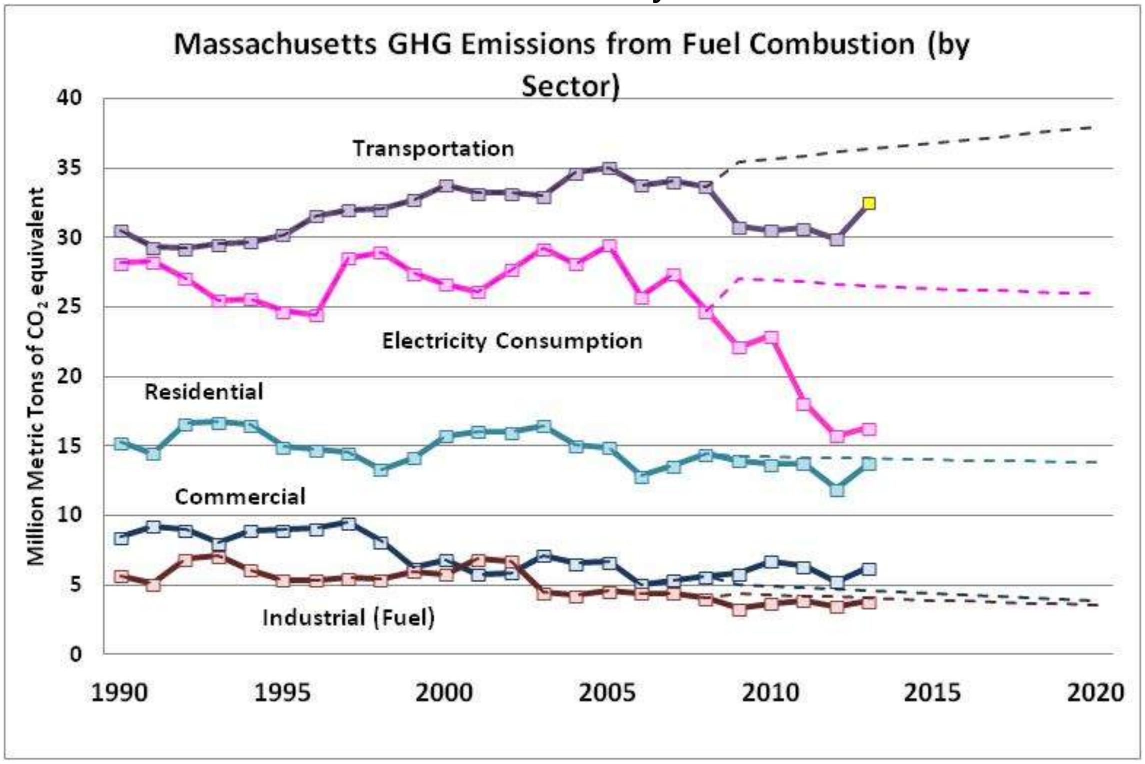
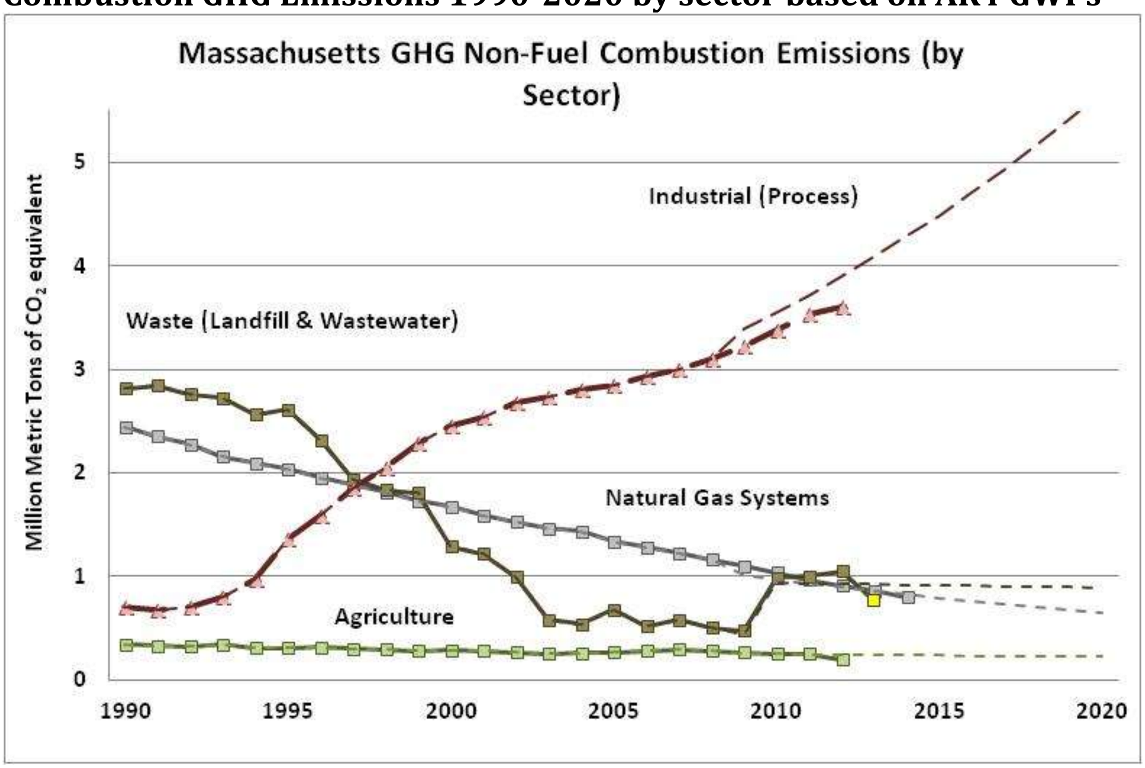


Figure 2B: Updated Massachusetts Baseline and BAU Projection of Non-Fuel Combustion GHG Emissions 1990-2020 by sector based on AR4 GWPs



Part 3: The Updated Massachusetts GHG Inventory

This updated 1990 Baseline/2020 BAU Projection contains complete GHG emissions through the year 2012, with partial emissions for 2013, using the updated data, methodologies, emission factors, and GWPs discussed in Appendix A. Table 2 presents a comparison of GHG emissions by year and GWP used. GHG emissions are shown for: 1) 1990, 2) 2011 (the last year for which a complete inventory was developed using the outdated GWPs), 3) 2020 BAU Projection, and 4) the 2020 Limit (25% below 1990). The first row in the table shows GHG emissions which were previously published by MassDEP and are based on SAR GWPs. The second and third rows in the table show GHG emissions which have been updated using revised sector methodologies, updated data sources, updated GWPs, and in some instances updated emission factors. The primary difference between the use of AR4 or AR5 GWPs in the Massachusetts GHG Inventory is the increased importance of CH_4 due to the larger AR5 methane GWP.[7]

Table 2: Comparison of Massachusetts 1990 and 2011 GHG Emissions, 2020 BAU and 2020 Limit Using Various GWPs ($MMTCO_2e$)

	1990 (Baseline)	2011 (Actual)	2020 BAU (Projection)*	2020 Limit: (25% below 1990)
Last published values (SAR)	94.4	80.0	94.0	70.8
Updated values (AR4)	94.5	78.6	92.7	70.8
Updated values (AR5)	94.9	78.8	92.8	71.2

*AR4 and AR5 BAU Projections based on complete emissions for 1990-2008; original published BAU did not have complete emissions through 2008 for all sectors.

The spreadsheets in Appendices C and D were calculated using AR4 and AR5 GWPs, respectively, and contain the GHG emissions upon which this inventory is based. The spreadsheets and the data presented have been updated to include changes and improvements to the grouping of some of the sectors, color coding, and graphs, as well as the presentation of the emissions by gas. The spreadsheets in Appendices E through Q contain data upon which the revised 2001 through 2013 Electricity Import emissions are based.

GHG emissions are provided for the following years:

- 1990 through 2010: now with revised sector methodologies, updated data sources, updated GWPs, and in some instances updated emission factors (see Appendix A below for details).
- 2011-2012: emissions are now complete for both years.
- 2013: incomplete for Mobile Sources methane (CH_4) and nitrous oxide (N_2O), Industrial Processes, Solid Waste (Industrial landfills), and Agriculture. These sectors will remain at least partially incomplete until the 2016 release of EPA's State GHG Inventory Tool (SGIT) (discussed in Appendix A).

[7] The decrease in the GWP for N_2O in AR5 has a smaller effect since N_2O is a much smaller part of the inventory. AR5 GWPs are used for the refrigerants sector for both the AR4 and AR5 rows in Table 2, as the underlying refrigerant use data source (EPA's Vintaging Model) skipped from SAR to AR5 without publishing refrigerant use based on AR4 GWPs.

MassDEP publishes a detailed inventory text document every three years as required by MGL chapter 21N, section 2, subsection (c), and a spreadsheet inventory update annually. Previous GHG inventory spreadsheets, supporting appendices, and texts are available[8] online.

[8] See http://www.mass.gov/eea/agencies/massdep/climate-energy/climate/ghg/greenhouse-gas-ghg-emissions-in-massachusetts.html#1.

Appendix A: GHG Emission Sources, Data Sources and Methodology

This section describes the sources of GHG emissions data, the methodologies that the Department used to develop the updated Massachusetts GHG inventory, and the differences between the sources of GHG emissions and the methodologies used to determine the original 1990 Baseline inventory and this update.

1. Sources of GHG Emissions

Combustion of Fossil Fuels. The biggest contribution to CO_2 emissions comes from burning fossil fuels for heat, transportation and electricity generation. Fossil fuel combustion also generates CH_4 and N_2O. Residential, Commercial, Industrial, Transportation and Electric Generation are the sectors in which fossil fuels are combusted.

Industrial Processes. The United States (US) Environmental Protection Agency (EPA) has identified 15 specific United States industrial processes that emit significant quantities of GHGs: Cement Production, Lime Manufacture, Limestone and Dolomite Use, Soda Ash Manufacture and Consumption, Iron and Steel Production, Ammonia Manufacture, Urea Consumption, Nitric Acid Production, Adipic Acid Production, Aluminum Production, Hydrochlorofluorocarbon (HCFC)-22 Production, Consumption of Substitutes for Ozone-Depleting Substances (ODS), Semiconductor Manufacture, Electric Power Transmission and Distribution, and Magnesium Production and Processing.

The industrial processes conducted in Massachusetts include Lime Manufacture, Limestone and Dolomite Use, Soda Ash Consumption, Urea Consumption, Consumption of Substitutes for ODS, Semiconductor Manufacture, and Electric Power Transmission and Distribution.

Natural Gas and Oil Systems. The US EPA identifies all phases of natural gas systems (including production, transmission, venting and flaring, and distribution) and petroleum systems (including production, refining, and transport) as sources of CH_4 and CO_2 emissions. Of these, only the transmission and distribution systems of natural gas are relevant for Massachusetts with emissions coming from leaks from miles of pipeline and numbers of services, customer meters, metering/regulating stations and venting.

Waste Management. The US EPA has identified several waste management activities that produce significant GHG emissions: municipal solid waste combustion, landfill methane generation, and wastewater disposal and treatment. All of these are found in Massachusetts.

Agriculture. The US EPA has identified several agricultural processes that are important GHG sources across the country: enteric fermentation (fermentation in the intestines of certain animals such as cows and sheep), manure management, management of plant residues retained in soil, legume cultivation, agricultural fertilizer use, rice cultivation, and burning agricultural residues. As with the industrial sources identified above, some of these activities are not found in Massachusetts or are at such *de minimis* levels that their contribution to GHGs in the

Commonwealth is negligible, if any (specifically, rice cultivation and agricultural residue burning are the two processes that do not occur in Massachusetts).

2. Data Sources and Methodologies for Developing the Updated 1990 Baseline/2020 BAU Projection

State and federal air pollution control programs have traditionally estimated air emissions of a wide variety of pollutants by applying pollutant-specific emission factors to measures of activities conducted by industrial sectors. The US EPA has developed a State GHG Inventory Tool (SGIT) which employs this methodology to estimate GHG emissions from sectors of concern in each state, based on the activities in key sectors in the state's economy. SGIT consists of a series of modules, or spreadsheets, which calculate emissions from the various sources of GHG. Gases included in the inventory are: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFC), perfluorocarbons (PFC) and sulfur hexafluoride (SF_6).

The SGIT default data set provides a basis for estimating and reporting annual GHG emissions by sector. For example, one large sector is CO_2 emissions from fossil fuel electrical generation plants in Massachusetts. The EPA SGIT methodology uses Massachusetts electric generator fuel use data (from the US Department of Energy's Energy Information Administration (EIA)'s State Energy Data System (SEDS)[9]) to calculate the electricity sector emissions from fuel combustion. The Department used SGIT's estimates of GHG emissions from fossil fuel electrical generation and other sectors to derive the inventory for Massachusetts.

The SGIT is updated annually (usually in January or February) for all emissions sectors. Each year, often by the end of June, EIA releases updates of the data that SGIT uses to calculate CO_2, CH_4 and N_2O emissions from fossil fuel and biomass combustion (except transportation sector CH_4 and N_2O, which SGIT calculates from other data). The Department developed this updated 1990 Baseline/2020 BAU Projection/GHG Inventory using the early 2015 release of EPA's SGIT populated with energy use by fuel and sector for most fuel types from the July 24, 2015 release of EIA's SEDS.

3. Estimating GHG Emissions from Imported Electricity Generation

It is important to recognize that approximately 45% of the electricity used in the Commonwealth is currently imported from power plants located in other states and in Canada. In order to account for the net electricity imports into Massachusetts from other New England states and import areas, as required by statute,[10] Massachusetts-specific generation and load data were utilized to develop an imported emissions estimate on the 'ElecImport' tab of Appendices C and D. The New England Independent System Operator (ISO-NE), which manages the New England electricity grid, publishes annual generation and load megawatt hour data for each New England

[9] See the EIA State Energy Data System (SEDS) at http://www.eia.doe.gov/emeu/states/_seds.html

[10] From GWSA, ""Statewide greenhouse gas emissions", the total annual emissions of greenhouse gases in the commonwealth, including all emissions of greenhouse gases from the generation of electricity delivered to and consumed in the commonwealth, accounting for transmission and distribution line losses, whether the electricity is generated in the commonwealth or imported; provided, however, that statewide greenhouse gas emissions shall be expressed in tons of carbon dioxide equivalents."

state. Data on electricity imported to New England from the adjacent New York, New Brunswick and Quebec control areas are also available from ISO-NE.

There are a variety of methods that can be used to estimate the emissions due to Massachusetts' consumption of electricity, including emissions associated with electricity generated out-of-state. MassDEP believes it is appropriate to consider GHG emissions associated with electricity consumption in regional and more state-specific contexts, since, due to the linked, regional nature of the New England electric grid, electricity generated in a state is not necessarily consumed in that state, even if that state is a net importer of electricity.

The tables in this inventory present emissions associated with electricity consumption using an approach that more directly accounts for emissions associated with electricity generated in Massachusetts, while an alternative regional approach is discussed further below. This approach assumes that all electricity generated in Massachusetts is used in Massachusetts (with the exception of in-state generation for which a renewable energy certificate is used out-of-state, as discussed further below). Thus, electric sector emissions in this approach are based on emissions from Massachusetts power plants plus a portion of emissions from power plants in the other New England states that generate more electricity than they use in a given year and in the adjacent control areas (New York, New Brunswick, Quebec) in years that New England received net imports of electricity from those control areas.

Under this approach, emissions due to Massachusetts' consumption of imported electricity were determined by apportioning to Massachusetts a share of any excess generation (and associated emissions) from each New England state that generates more electricity than it uses. Thus, the inventory includes a share of the emissions associated with each electricity-exporting state's exported electricity, as calculated from EIA fuel heat content data. (These data are the basis of EPA's SGIT estimate of each state's CO_2, CH_4 and N_2O emissions from fossil fuel combustion and CH_4 and N_2O emissions from biomass combustion). Similarly, the inventory apportions to Massachusetts a percentage of the megawatt hours of losses (and associated emissions) due to pumped hydro and of the net annual imports into the ISO-NE grid from the New York, New Brunswick and Quebec grids.[11] Emissions from the Canadian Provinces were calculated using Environment Canada's National Inventory Report.[12]

Massachusetts also considers electric sector emissions in a broader regional context, due to the linked nature of the New England electric grid, in which demand for electricity in one state

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[11] The megawatt hours of imports and of losses associated with pumped hydro were found in ISO-NE "Net Energy and Peak Load by Source" report at http://www.iso-ne.com/static-assets/documents/2015/02/gen_nel_iso_states.xls. The megawatt hours of losses associated with pumped hydro were apportioned to each New England state according to that state's fraction of total New England load.

[12] The New Brunswick and Quebec GHG emissions are based on a Canadian report, the most recent of which is the *National Inventory Report 1990–2013: Greenhouse Gas Sources and Sinks in Canada*, Environment Canada, April 17, 2015 at http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/8812.php. See Table A13-5 "Electricity Generation and GHG Emission Details for New Brunswick" and Table A13-6 "Electricity Generation and GHG Emission Details for Quebec"). MWh of electricity generated from wood combustion are obtained from Statistics Canada *Table 127-0006 - Electricity generated from fuels, by electric utility thermal plants, annual (megawatt hour)*, Statistics Canada, CANSIM (database), at http://www5.statcan.gc.ca/cansim/a26?lang=eng&id=1270006&p2=17 (accessed on April 21, 2015).

influences electricity generation in other states. An alternative electricity consumption emissions approach, documented on the far right of the 'ElecImport' tab of Appendices C and D, involves first determining the fraction of New England electricity (in MWh) that is consumed in Massachusetts. Massachusetts is then assumed to be responsible for that same fraction of the GHGs emitted while generating that electricity. Thus, electric sector emissions in this approach are based on the total New England GHG emissions from electricity generation plus GHG emissions associated with electricity imported from the adjacent control areas (New York, New Brunswick, Quebec) in years that New England received net imports of electricity from those control areas; this total was multiplied by the ratio of Massachusetts to New England electricity consumption.

The load, generation, and emissions data have been updated in the 'ElecImport' and 'EIA Adjust' tabs of Appendices B and C.

4. Updated Data Sources and Methodology Changes

Additional data sources have become available since the publication of the initial 1990 Baseline/2020 BAU Projection in July 2009. The Massachusetts and EPA GHG Reporting programs began collecting data with the 2010 emissions year and now provide some facility-specific data that this inventory uses in place of SGIT defaults. GHG emissions data from these reporting programs can be obtained from the Massachusetts *Climate Registry Information System* (CRIS)[13] and the EPA *Facility Level Information on GreenHouse Gases Tool* (FLIGHT).[14] This inventory replaces certain SGIT data with Massachusetts facility-specific data, particularly in the industrial processes and solid waste sectors where the SGIT state level emissions are derived from national emissions apportioned to states based on population or sales. Another one of the advantages of FLIGHT and CRIS data is that they are often available much sooner than SGIT.

In certain sectors, refinements have been made to the input or output of SGIT using facility data specific to Massachusetts (e.g., the Massachusetts Water Resources Authority (MWRA) digester gas data in the wastewater sector). For other sectors, such as imported electricity and natural gas systems, emissions are estimated outside of SGIT. Finally, for consistency, emissions from certain sectors have been reassigned to other sectors to align this inventory with other inventories or tracking systems which contribute to this inventory (e.g., emissions from municipal waste combustors (MWCs) that generate electricity have been moved to the electricity sector).

Specifically, the changes between the initial 1990 Baseline/2020 BAU Projection and this Updated 1990 Baseline/2020 BAU Projection/Inventory are as follows:

<u>Solid Waste - Landfills.</u> Massachusetts is one of the states for which EPA's SGIT estimates *negative* landfill sector methane emissions due to data gaps. The 2015 SGIT Solid Waste module estimates steadily decreasing CH_4 emissions from Massachusetts landfills from 1990 to 2008, ultimately estimating negative methane starting in 2010 (earlier releases of SGIT had produced negative CH_4 emissions prior to 2010). Fortunately, Massachusetts landfills were required to

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[13] See http://www.mass.gov/eea/agencies/massdep/climate-energy/climate/approvals/ma-greenhouse-gas-emissions-reporting-program.html#3
[14] See http://ghgdata.epa.gov/

report to Massachusetts and EPA beginning with their 2010 GHG emissions. This inventory uses emissions from FLIGHT rather than CRIS for various reasons, including that the calculations in EPA FLIGHT are more transparent than in Massachusetts CRIS, and FLIGHT has updated to the AR4 GWPs while CRIS has not. Emissions for industrial landfills are still obtained from SGIT as no industrial landfill sources in Massachusetts report to FLIGHT.

Solid Waste - Municipal Waste Combustors (MWCs). New data sources have led to a greater understanding of the facilities combusting municipal solid waste (MSW) in Massachusetts enabling the Department to fill in some of the remaining gaps in the GHG inventory, and to shift the emissions from the combustion of solid waste into more representative sectors (i.e., electric generation and industrial fuel use). Earlier inventories calculated the emissions from tons of waste combusted in the SGIT Solid Waste module, and placed the emissions from MWCs in the Solid Waste sector. GHG emissions for each of the seven MWCs in Massachusetts are available from EPA FLIGHT beginning with 2010. The Department prefers to use the most specific Massachusetts data available for this inventory, because Massachusetts has implemented regulations encouraging recycling and prohibiting the disposal as waste of materials that have other uses, which can result in lower GHG emissions (e.g., due to increased plastics recycling and thus reduced MWC emissions from combustion of plastic). Therefore, emissions from FLIGHT are used beginning with the year 2010.

There are seven existing MWCs in Massachusetts. Six of these generate electricity for distribution on the grid. The emissions from these six MWCs have been moved out of the Solid Waste sector and into the Electricity sector. This aligns this sector with the Electricity Imports calculations, which includes the MWh and emissions from MWCs in the base calculation (NAICS-22 Non-Cogen in EIA Form 923), and with the NEPOOL-GIS tracking System, which tracks RPS-eligible Municipal Solid Waste and Trash-to-Energy Renewable Energy Certificates (RECs) that are purchased by retail sellers of electricity and settled into their various state subaccounts for compliance with state Renewable Portfolio Standards (RPS). (See below for details on Imported Electricity method changes to account for RPS-eligible RECs.) For these six MWCs, GHG emissions are obtained from SGIT (after removing the seventh MWC) for 1990-2009 and from FLIGHT for 2010 to present.

Industrial sector - Waste Combustion. The seventh MWC in Massachusetts generates primarily steam for use by local manufacturing. With this 1990 baseline update, its emissions are being moved to the Industrial sector. This requires subtracting the approximate tons of waste for this MWC from the total tons of waste used to calculate GHGs from MSW for the Electricity sector from 1990 until 2009 (see above) so that they are not double-counted. EPA FLIGHT emissions are used beginning with 2010.

During the 1990s there were other several other MWCs that combusted MSW to generate steam for the Industrial sector. EIA's SEDS appears to include MSW combustion at the existing industrial MWC and the other industrial MWC facilities until they shut down, and CH_4 and N_2O were previously calculated by entering this data as "Other" fuel in the Stationary Combustion module. (CO_2 from this waste was not calculated as the Department was unable to determine the disposition of this waste.) There appears to be a single MWC combusting MSW for the Industrial sector after the year 2000.

Emissions from waste combusted in the Industrial sector are now calculated on the 'Solid Waste' tab of Appendices C and D, applying the EIA national annual biogenic/non-biogenic MSW split to EIA SEDS heat input data for the years 1990-2009. EPA's FLIGHT emissions are used beginning with 2010. This now allows the Department to calculate non-biogenic CO_2, CH_4 and N_2O from the combustion of the non-biogenic portion of EIA SEDS industrial waste combustion on the 'Solid Waste' tab, and to include those emissions in the Industrial Waste sector. CH_4 and N_2O from the combustion of biogenic waste has been added to the emissions for this fuel source (see section 6 of this Appendix A for a discussion of biogenic waste).

<u>Wastewater.</u> The SGIT methodology calculates the CH_4 and N_2O emissions from the disposal and treatment of municipal and industrial wastewater. SGIT uses a state's population to calculate the quantity of emissions. In Massachusetts, MWRA provides wastewater treatment service to approximately one third[15] of the state's population. The MWRA processes its sewage sludge at Deer Island through 12 anaerobic digester "eggs" which break sludge down into biogas composed primarily of methane gas, with some carbon dioxide, solid organic byproducts, and water. This biogas is captured and burned in boilers and steam generators to produce useful steam and electricity for the site.[16] In order to avoid double-counting the emissions from this biogas (as CH_4 in the wastewater sector and as CO_2 once combusted), the population served by the MWRA system[17] has been removed from the SGIT Wastewater module by reducing the state population used in the calculations by one third, beginning with the year 2000 (8 of the eggs came online in 1995, the other 4 in 1998).

The digested sludge from the eggs is then further processed into a pelletized-fertilizer product. A 2011 report on anaerobic digestion by MassDEP notes that 30% of Massachusetts biosolids are used as fertilizer, with 8% being used in Massachusetts and the remainder out-of-state.[18] In order to avoid double-counting the emissions from these biosolids (as N_2O in the Wastewater sector and as fertilizer in the Agricultural sector), the 30% of biosolids used as fertilizer was excluded in the SGIT Wastewater module, reducing Wastewater sector N_2O emissions.

<u>Industrial Processes - Lime Manufacture.</u> Emissions for lime manufacturing, historically absent for long stretches of time from the EPA SGIT inventory for Massachusetts and thus interpolated for the missing years, now come from EPA FLIGHT beginning with 2010 emissions.

<u>Natural Gas Systems.</u> The SGIT Natural Gas and Oil Systems module does not contain certain values needed to determine leak emissions from the transmission or distribution of natural gas. For natural gas transmission system emissions, MassDEP acquired the number of miles of transmission pipeline from the US Department of Transportation Pipeline and Hazardous

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[15] Population for MWRA towns for 2000 and 2010 obtained from US Census website.

[16] According to the MWRA, a small amount of biogas is flared. Flare data come from MWRA. The CH_4 and N_2O emissions from the combustion of this biogas are included in the non-biogenic portion of this inventory. See section 6 of this Appendix A for a discussion of flare biogenic emissions.

[17] There are other smaller treatment plants serving smaller numbers of municipalities which MassDEP may also be able to account for in future inventories.

[18] See Figure 7 in "Tapping the Energy Potential of Municipal Wastewater Treatment: Anaerobic Digestion and Combined Heat and Power in Massachusetts," by MassDEP, July 2011 at http://www.mass.gov/eea/docs/dep/water/priorities/chp-11.pdf.

Materials Safety Administration (PHMSA) "Distribution, Transmission & Gathering, and Liquid Annual Data"[19] collected from the natural gas transmission companies operating in Massachusetts, and used the SGIT default emission factors and number of gas transmission and storage compressor stations.

However, emissions from the distribution system are now calculated on the 'NatGas Systems' tab of Appendices C and D. The data for distribution systems are now obtained from EIA and from the local distribution companies (LDCs). The leak emission factors have also been updated. Emissions are calculated for distribution pipeline miles, services, customer meters, metering and regulating stations, venting, pipeline blow downs, dig-ins, and pressure release valves.

Emissions from the natural gas distribution system consist of leakage of the methane portion of natural gas. Determining emissions from the system requires knowledge of emission factors for the various physical components composing the distribution network, and knowledge of the number of such components in the network. Prior to this inventory update, the 2 components of the distribution system that were used in determining emissions for this sector were the miles of pipeline made of cast iron, cathodically-protected steel, cathodically-unprotected steel and plastic, and the total number of service lines to homes and businesses and the number of services made of cathodically-protected steel and cathodically-unprotected steel (available from the PHMSA "Distribution, Transmission & Gathering, and Liquid Annual Data" collected from the local distribution companies in Massachusetts[20]).

This inventory update estimates emissions using the miles of pipeline and number of services made of cast and ductile iron, cathodically-protected steel, cathodically-unprotected steel, plastic, copper, and other. Additional distribution system components that have been added in this inventory update include the number of residential, commercial and industrial customer meters (available from the US Department of Energy's Energy Information Administration data collected from the local distribution companies in Massachusetts[21]) and the number of metering and regulating stations in use in 1990 and currently (obtained from the local distribution companies in Massachusetts).

Prior to this inventory update, the emission factors used to estimate this sector's emissions from pipelines and services were those found in EPA's SGIT. This inventory update uses a combination of emission factors from SGIT, from an ICF report[22] for the Massachusetts Department of Public Utilities, and from an April 2015 study[23] that measured equipment emissions to estimate current emission factors. The April 2015 emission factors were combined with the most recent miles of pipeline, number of services and number of metering and regulating stations (for 2014). The ICF-recommended emission factors were combined with the 1990 miles of pipeline, number of services and number of metering and regulating stations, except for plastic pipelines, for which the SGIT emission factor was used since it is more

[19] See http://www.phmsa.dot.gov/pipeline/library/data-stats/pipelinemileagefacilities
[20] Ibid.
[21] See http://www.eia.gov/beta/api/qb.cfm?category=481105
[22] *Lost and Unaccounted for Gas*, December 23, 2014, see http://www.mass.gov/eea/docs/dpu/gas/icf-lauf-report.pdf
[23] *Direct Measurements Show Decreasing Methane Emissions from Natural Gas Local Distribution Systems in the United States*, April 13, 2015, see http://pubs.acs.org/doi/abs/10.1021/es505116p

representative of the higher emissions rate in 1990. The emission factors for miles of pipeline and number of services from 1991 through 2013 were interpolated using the emission factors for 1990 and 2014. The GHG emissions for metering and regulating stations from 1991 through 2013 were interpolated using the emissions calculated for 1990 and 2014.

For residential and commercial customer meters, and venting (consisting of pipeline blowdowns, pipeline digins and pressure relief valves, with emission factors expressed per pipeline mile) the emission factors from the ICF report were used for all years, as the April 2015 study did not assess such emission factors. For industrial meters, the emission factor was developed from ICF's underlying source document[24] to exclude an extreme outlier that would otherwise indicate industrial meters to be a greater source of emissions than the sum of all other distribution system emissions, and would represent unsafe operation that does not match the Massachusetts experience.

Imported Electricity Generation. This inventory integrates a change into the imported electricity methodology to address the Massachusetts Department of Energy Resources' Renewable Portfolio Standard that requires increasing amounts of renewable power be sold each year, beginning with 2003.[25] Other New England states have similar programs. These renewable power sales are documented through the use of Renewable Energy Certificates (RECs). While the electric-sector inventory methodology (described in section 3 of this Appendix A) indirectly[26] accounts for the use of RECs, this inventory has been expanded to more explicitly and fully account for the purchase of RECs by Massachusetts retail electricity sellers. Since the RPS requires increasing amounts of renewable energy over time, it is possible that the previous methodology would have caused an increasingly less-accurate Massachusetts GHG inventory over time. Prior to this inventory update, only inventories for 2009 and later accounted for REC use.

For example, if Massachusetts retail electricity suppliers buy RECs from a power plant in a state that is a net importer of electricity, the inventory methodology to-date has not reflected emissions associated with such RECs. Likewise, if RECs associated with power generated at a Massachusetts in-state power plant are sold out-of-state, the Massachusetts inventory to-date has included the emissions (or lack thereof, if the facility is non-emitting) from such a plant, when they should more appropriately be allocated to the state that purchased the RECs.

Therefore, beginning with 2003, MassDEP has expanded the inventory's electric-sector methodology to address RECs generated in one New England state or adjacent control area, but used in another.[27] Imported electricity emissions are now calculated on separate spreadsheets

[24] See "Field Measurement Program to Improve Uncertainties for Key Greenhouse Gas Emission Factors for Distribution Sources" Gas Technology Institute, November 2009, at http://www.otd-co.org/reports/Documents/77b_OTD-10-0002_GHG_Emission_Factors_FinalReport_v2.pdf

[25] See http://www.mass.gov/eea/energy-utilities-clean-tech/renewable-energy/rps-aps/

[26] The indirect accounting did not consider whether electricity was generated by RPS-qualified generators. To the extent that RPS-qualified generation occurred in a state that generated more electricity than it used, a portion of the emissions of such generation were assigned to Massachusetts under the indirect accounting methodology. The inventory now accounts for the state that RECs settle in.

[27] As documented in Appendices C and D, this methodology builds off MassDEP work associated with GHG reporting by Massachusetts' retail sellers of electricity.

(Appendices G through Q). The data sources for each state's GHG emissions have been improved and are now calculated from a more robust facility-specific data set that incorporates Regional Greenhouse Gas Initiative (RGGI) emissions for New England states and EIA's Form 923[28] facility heat input data. In addition, biogenic, as well as non-biogenic, emissions have been included. Interim spreadsheets (Appendices E and F) have been used for the years 2001 and 2002. The interim spreadsheets also use the RGGI and EIA Form 923 data to derive emissions and introduce biogenic emissions from imported electricity; however, they pre-date the RPS program and therefore do not need to address RECs.

5. Global Warming Potential and Emission Factor Updates

Updated Global Warming Potentials (GWPs). The 1990 Baseline/2020 BAU Projection published in 2009 used the GWPs from the IPCC Second Assessment Report (SAR), published in 1996, consistent with the US National GHG Inventory Reports. The IPCC has published several assessment reports since that time with updated GWPs, most recently in the Fourth Assessment Report (AR4) in 2007 and the Fifth Assessment Report (AR5) in 2013. To comply with United Nations Framework Convention on Climate Change (UNFCCC) international reporting standards, the US National GHG Inventory Report, published in April 2015, moved to the AR4 GWPs (with the exception of substitutes for ozone depleting substances (ODS)/refrigerant gases as noted below). That report retroactively assigns the AR4 GWPs to all emissions back through 1990.

The EPA GHG reporting program also moved to the AR4 GWPs in 2015, recalculating all facility emissions back through the earliest year reported to EPA (2009 or 2010, depending on the sector). EPA's January 2015 SGIT modules also updated all GHG emissions with AR4 GWPs retroactive to 1990 (again with the exception of ODS substitutes/refrigerants). The Massachusetts GHG Reporting Program Climate Registry Information System (CRIS) is still using SAR GWPs, but only negligible quantities of CH_4 and N_2O from CRIS[29] are included in this inventory.

The Department is seeking comment on whether AR4 or AR5 GWPs should be used when this updated 1990 Baseline/2020 BAU Projection is finalized. AR4 could be an appropriate choice because all national inventories are being updated to AR4. AR5 could be an appropriate choice as it incorporates the latest science, but would mean Massachusetts' GHG inventory would not be directly comparable to GHG inventories of other jurisdictions.

Table A1 below provides the GWPs from IPCC assessment reports for a small sample of GHGs, showing the difference, as a percentage, between the SAR GWPs used in the initial 1990 baseline/2020 BAU Projection and the AR4 and AR5 GWPs being considered for this updated 1990 Baseline/2020 BAU Projection. Of note with the release of the AR5 GWPs are the separation of methane and fossil methane, and the inclusion of climate-carbon feedbacks. The Department is considering incorporating this new methane and feedback information into future inventories, after guidance for their use has had more time to develop at national and

[28] The EIA Form 923 data is the source of the EIA SEDS data.
[29] Specifically, this inventory incorporates CRIS CH_4 and N_2O emission from the combustion of landfill gas in landfill flares and in non-grid-connected engines.

international levels (see the cautionary note from IPCC below Table A1 regarding the use of fossil methane values). Also of note with AR5 is the listing of new ODS substitutes that have been manufactured in recent years.

Table A1: 100-Year Global Warming Potentials (GWPs) - for selected GHGs

GHG	Second Assessment Report (SAR)	Fourth Assessment Report (AR4)	Difference between SAR and AR4	Fifth** Assessment Report (AR5)	Difference between SAR and AR5
	1996	**2007**	**%**	**2014**	**%**
CO_2	1	1	0.0	1	0.0
CH_4/Fossil CH_4*	21	25	19.0	28/30	33.3/42.9
N_2O	310	298	-3.9	265	-14.5
SF_6	23,900	22,800	-4.6	23,500	-1.7
HFC-134a	1,300	1,430	10.0	1,300	0.0
HFC-1234yf				<1	
C_2F_6 (aka PFC-116)	9,200	12,200	32.6	11,100	20.7
CF_4 (aka PFC-14)	6,500	7,390	13.7	6,630	2.0
c-C_4F_8 (aka PFC-318)	8,700	10,300	18.4	9,540	9.7

* "Metric values for CH_4 of fossil origin include the oxidation to CO_2 (based on Boucher et al., 2009). In applications of these values, inclusion of the CO_2 effect of fossil methane must be done with caution to avoid any double-counting because CO_2 emissions numbers are often based on total carbon content. Methane values without the CO_2 effect from fossil methane are thus appropriate for fossil methane sources for which the carbon has been accounted for elsewhere, or for biospheric methane sources for which there is a balance between CO_2 taken up by the biosphere and CO_2 produced from CH_4 oxidization."
** Climate-carbon feedbacks in this table are included only for CO_2.

Sources:
For GWPs, see http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml#1.
For Table Notes, see: Table 8.A.1, *Climate Change 2013: The Physical Science Basis*, Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, see http://www.ipcc.ch/report/ar5/wg1/.

Updated Combustion Emission Factors (EFs). The Department used EFs from EIA and IPCC when developing the 1990 Baseline/2020 BAU Projection published in 2009. Now, additional EFs from EPA's GHG Reporting Rule[30] are available, and were used in calculating emissions from imported electricity and biogenic fuel sources. The EFs used in this inventory are selected by giving preference to EFs developed for areas the most geographically proximate to Massachusetts (e.g., preference for US EFs over international default EFs) and temporally recent (e.g., preference for more recent EFs over older EFs). This prioritization results in this inventory using: EIA's CO_2 EFs by fuel type where available to calculate CO_2 emissions; EPA's EFs by fuel type to calculate CO_2 emissions where EIA EFs were not available and to calculate CH_4 and N_2O emissions; and IPCC EFs by fuel type to calculate GHG emissions where EIA and EPA EFs were not available.

[30] See Table C-1 at http://www.gpo.gov/fdsys/pkg/CFR-2014-title40-vol21/pdf/CFR-2014-title40-vol21-part98-subpartC-appC.pdf and Table C-2 at http://www.gpo.gov/fdsys/pkg/CFR-2014-title40-vol21/pdf/CFR-2014-title40-vol21-part98-subpartC-appC-id656.pdf.

6. Biomass Biogenic CO_2 Emissions, Forest Sequestration and Land Use Change Emissions

Biogenic GHG emissions are the emissions of CO_2 that result from land use change and forest sequestration, and from the combustion of biogenic materials. (Biogenic material means plant or animal material, excluding fossil fuels.) Emissions from land use change include the one-time release of previously sequestered soil carbon due to the soil disturbance involved. Given the lack of annual data for biogenic sources and sinks, the Department has estimated biomass biogenic CO_2 emissions from forest sequestration and land use change. Despite the challenges in accurately calculating these data on an annual basis, it appears that other, non-annual, data available for the biomass sector are sufficient, and their magnitude is significant enough that it is important to continue to track them going forward. Details of land use change and forest sequestration emissions data can be found below and on the 'Forest & Land Use Change' tab of Appendices C and D.

Biogenic CO_2 emissions result from the combustion of biomass fuels, including: biofuels, such as ethanol (used in vehicles and in the commercial and industrial sectors), wood and paper (largely combusted at residences and electric generation plants), landfill gas (either flared or combusted for electric generation), biogas (from anaerobic digestion of sludge waste), and the biomass portion of municipal solid waste (combusted at waste-to-energy plants). In presenting the biogenic CO_2 emissions associated with the combustion of biomass, this inventory uses the convention for biogenic sources adopted by the World Resources Institute, The Climate Registry, and others, which report biogenic CO_2 emissions separately from other GHG emissions. Hence, Tables 1 and 2 do not include CO_2 released during combustion of biomass.[31]

For this updated 1990 Baseline/2020 BAU Projection, CO_2 emissions due to biomass combustion were calculated using data from EIA's July 2015 data release, from the Massachusetts and EPA GHG Reporting Programs (e.g., Massachusetts CRIS landfill oxidation and EPA FLIGHT MWC data), and from data obtained directly from facilities (i.e., MWRA). These emissions calculations can primarily be found on the 'Biogenic Calcs' tab of Appendices C and D. CH_4 and N_2O emissions from wood and electric sector MSW combustion continue to be calculated in an SGIT module. CO_2 emissions from Massachusetts' consumption of imported electricity generated from biomass combustion were determined using the methodology discussed above for imported electricity generation.

Biogenic GHG emissions for 1990 and 2012 are summarized in Table A2 and Figure A1 below. While there are more sources of data available for biogenic emissions now than there were for the initial 1990 Baseline/2020 BAU Projection, the data continue to present some limitations. For instance, to the extent that biomass harvested in Massachusetts is also combusted in Massachusetts, such emissions are double-reported as combustion and land use change emissions. Some additional limitations include: carbon sink data that are only included for forestry; annual forest sink data points, for the years in between forest surveys, that are based on interpolated rather than measured data; and municipal solid waste combustion whose biogenic

[31] Note, CH_4 and N_2O emissions associated with biomass combustion are included in emissions in Table 1, as part of the Stationary Combustion, Waste, and Mobile Combustion categories. CO_2 emissions associated with biomass combustion are not included in Tables 1 or 2.

fraction is estimated using the national fraction from 1990 to 2004.

Table A2: Biogenic GHG Emissions ($MMTCO_2e$)

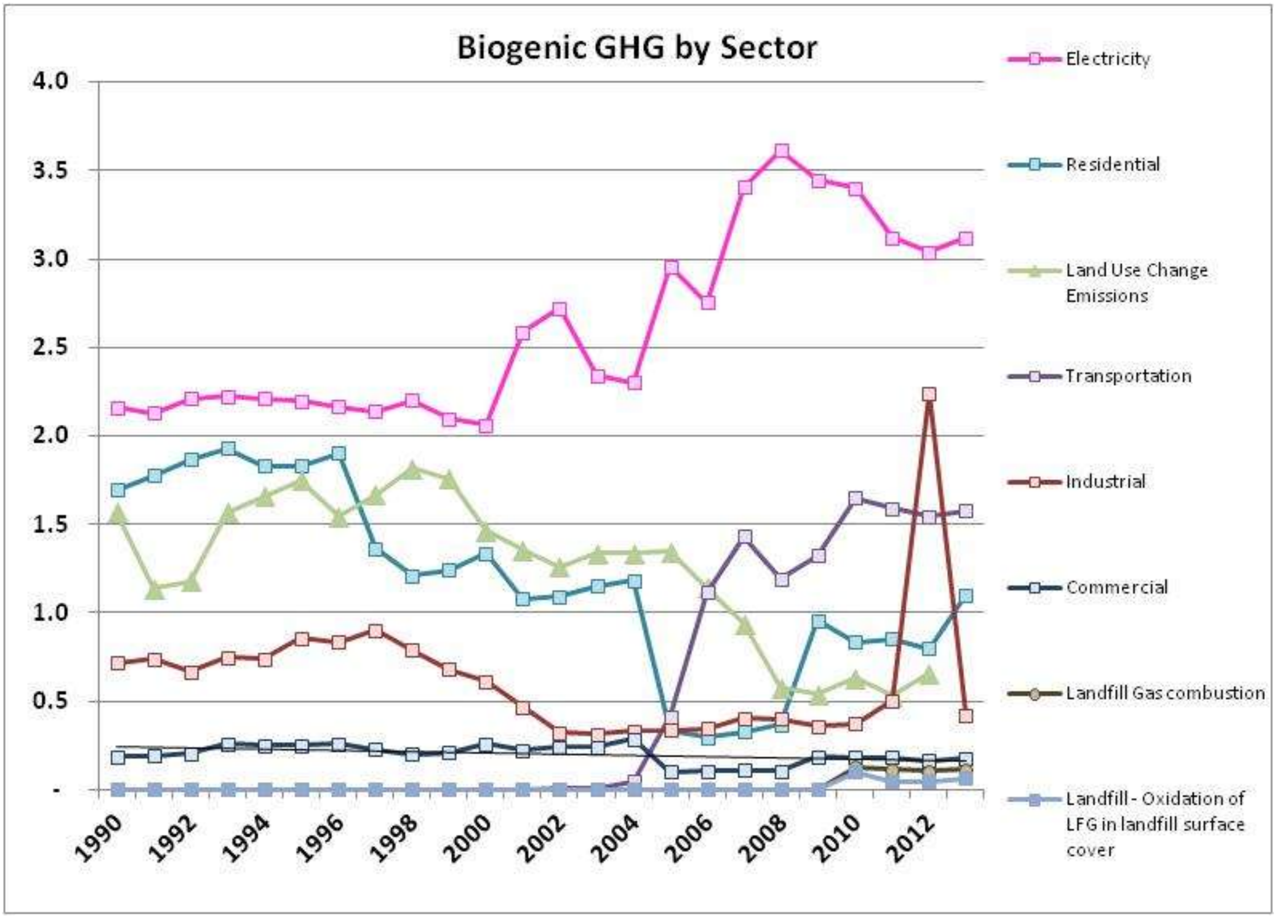
	1990[32]	2012
Total Combustion Emissions	4.8	7.9
Residential from Fuel Combustion	1.7	0.8
Commercial from Fuel Combustion	0.2	0.2
Industrial from Fuel Combustion	0.7	2.2
Transportation from Fuel Combustion	-	1.5
Electricity from Fuel Combustion	2.2	3.0
Electric Generation	-	0.3
Electric Generation from Waste	2.2	1.6
Electricity Imports	-	1.1
Waste Landfill Gas Combustion (non-electricity)	-	0.1
Landfill –Landfill Gas in flares, engines & turbines	-	0.1
Wastewater – Landfill Gas in flares	-	0.001
Oxidation of Landfill Gas in surface cover	-	0.05
Total Combustion, Imports & Oxidation	4.8	7.9
Forest Sequestration	-8.3	-11.8
Land Use Change Emissions	1.6	0.7
Net Biogenic CO_2 Emissions	**-1.9**	**-3.2**

Notes:

- Due to rounding to 1 decimal place, some totals appear higher or lower than the simple sum of the sectors.
- To the extent that biomass harvested in Massachusetts is combusted in Massachusetts, associated CO_2 emissions are double-reported in combustion and land use change emissions.

[32] Blank rows are due to either lack of data, or changes in combustion fuels (e.g., ethanol) over time.

Figure A1: Estimated Massachusetts Biogenic CO_2 Emissions 1990-2012 by sector



Note: To the extent that biomass harvested in Massachusetts is combusted in Massachusetts, associated CO_2 emissions are double-reported in combustion and land use change emissions.

The Department made the following methodology changes with this updated 1990 Baseline/2020 BAU Projection for the biogenic CO_2 emissions from the combustion of biomass fuel sources.

Solid Waste/Landfills. Beginning with 2010 emissions, MassDEP obtains biogenic CO_2 emissions from the Massachusetts GHG Reporting Program CRIS for the oxidation of landfill gas and for the combustion of landfill gas in landfill flares and in non-grid-connected engines.[33] (The CH_4 and N_2O emissions from combustion of this landfill gas are included in the non-biogenic portion of this inventory.)

Solid Waste - Municipal Waste Combustors (MWC). As discussed above, GHG emissions from the six electricity-generating MWCs have been moved to the Electric sector. Biogenic CO_2 emissions have been calculated for MSW combustion in the Electric sector, by applying the EIA national annual biogenic/non-biogenic MSW split to EIA SEDS heat input data from 1990-2000, and then to EIA Form 923 heat input data from 2001-2004. EIA Form 923 heat input data is used

[33] In contrast, beginning with 2006 emissions, MassDEP determines grid-connected landfill gas engine CO_2 emissions based on EIA heat input data.

directly from 2005-2009 and EPA FLIGHT provides facility specific emissions beginning with 2010. (The CH_4 and N_2O emissions from combustion of the biogenic portion of MSW are included in the non-biogenic portion of this inventory.)

Industrial sector – Waste Combustion. As discussed above, GHG emissions from the seventh waste-to-energy MWC have been moved to the Industrial sector, along with the other industrial MWCs that operated during the 1990s. Biogenic CO_2 emissions have been calculated from EIA SEDS from 1990-2009 using the national split methodology discussed above. EPA FLIGHT emissions are used beginning with 2010. (The CH_4 and N_2O emissions from combustion of the biogenic portion of industrial waste are included in the non-biogenic portion of this inventory.)

Wastewater. As discussed in section 4, the biogas from MWRA's Deer Island anaerobic digesters is combusted primarily to produce electricity and steam for the facility, with some biogas being flared. The CO_2 emissions from the combustion of this biogas for energy production are included as Commercial sector biogenic emissions. The CO_2 emissions from the combustion of this biogas in the flare are included as Wastewater sector biogenic emissions. (The CH_4 and N_2O emissions from the combustion of this biogas are included in the non-biogenic portion of this inventory.)

Imported Electricity. Biogenic emissions from imported electricity were not included in the original 1990 Baseline/2020 BAU Projection and data are still largely unavailable for 1990-2000. The calculation of biogenic emissions from imported electricity begins with 2001 and benefited from the same methodology improvements discussed above in section 4. Emissions are calculated using the spreadsheets in Appendices E and F for 2001-2002, and the GHG Inventory Import spreadsheets in Appendices G through Q beginning with 2003. (The CH_4 and N_2O emissions from combustion of biogas are included in the non-biogenic portion of this inventory.)

7. Other Methodological Issues

Several potentially significant sources of GHGs are not included in the Massachusetts inventory due primarily to the difficulty in quantifying emissions in these sectors. These notably include GHG emissions and sequestration from embodied emissions, and Black Carbon.

Embodied Emissions.

- Traditional emissions inventories (including the SGIT) and projections are based on the production of emissions in a geographic area. But emissions can also be generated by the manufacture of products elsewhere and the transportation of these products into Massachusetts (and thus "embodied" in these products). With the exception of electricity sector emissions (discussed in section 3 above), emissions that occur during the manufacture of products used in Massachusetts are not included in this inventory. For example, in the case of gasoline, emissions from combustion in vehicles in Massachusetts are counted, but emissions from extracting and refining petroleum used in Massachusetts are not. This treatment of "lifecycle" or "embodied" emissions is consistent with the structure of GWSA. It also recognizes the difficulty in obtaining detailed information about how items imported into Massachusetts are produced, and ensures that the same emissions are not double counted in more than one jurisdiction.

- On the other side of the equation, some embodied emissions are essentially sequestered when they are stored in landfills or used for the manufacture of long lifespan infrastructure. Some examples of sequestered fossil fuels include plastics in landfills, asphalt in roads and a portion of construction materials in permanent buildings. While EPA's SGIT does exclude the non-energy consumption of asphalt and road oil from reported emissions, the fate of most other materials consumed in Massachusetts is not addressed in the inventory.

Massachusetts data on consumption of such goods is not available. Detailed data on imports of such goods to the state by industry, or where the imports come from, is also not available. At best, the Department can only make rough extrapolations from national data. Further, the available academic studies do not have data for the GWSA base year of 1990. One study presents 1997 – 2004 data, making it difficult to extrapolate backward to 1990.[34] Nor are there good forecasts of where manufacturing will take place in 2020, what Massachusetts consumption will be in that year, or what the carbon intensity factors will be in future years for each industry, in each country and state.

For these reasons, the Department cannot make reasonable estimates of net GHG imports to the Commonwealth in 1990, nor project them to 2020. However, because of the importance of such impacts, and possible future policy options that could address this, the Department will continue to track research in this area.

<u>Black Carbon.</u> Black Carbon is one of the short-lived climate pollutants (SLCP).[35] It is "the most strongly light-absorbing component of particulate matter (PM), and is formed by the incomplete combustion of fossil fuels, biofuels, and biomass."[36] Over 50% of the black carbon emissions in the U.S. come from mobile sources, particularly diesel engines. The Department, in partnership with federal, state and private entities, has been working to reduce diesel emissions from on- and off-road sources, implementing many grant programs to support installation of diesel retrofit controls (e.g., diesel particulate filters and diesel oxidation catalysts). Although the Department does not have black carbon emissions data for 1990 to include in the GHG inventory, diesel emissions reduction efforts in Massachusetts have been ongoing for many years. For a list of the diesel reduction programs in Massachusetts see Appendix B "MassDEP Emission Reduction Programs for Mobile Sources."

EPA projects that black carbon emissions will decline 86% from 2005 by 2030 largely due to

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[34] "Embodied Environmental Emissions in U.S. International Trade," 1997-2004," Christopher L. Weber and H. Scott Matthews, Environmental Science & Technology, 2007; "CO_2 Embodied in International Trade with Implications for Global Climate Policy," Glen P. Peters and Edgar G. Hertwich, Environmental Science and Technology, Vol. 42, No. 5, 2008.

[35] As indicated by the California Air Resources Board "Short-lived climate pollutants are powerful climate forcers that remain in the atmosphere for a much shorter period of time than longer-lived climate pollutants, such as carbon dioxide (CO_2). Their relative potency, when measured in terms of how they heat the atmosphere, can be tens, hundreds, or even thousands of times greater than that of CO_2. The impacts of short-lived climate pollutants are especially strong over the short term. Reducing these emissions can make an immediate beneficial impact on climate change." http://www.arb.ca.gov/cc/shortlived/shortlived.htm

[36] See US EPA Black Carbon webpage at http://www.epa.gov/blackcarbon/basic.html and EPA's *Report to Congress on Black Carbon*, March 2012, at http://www.epa.gov/blackcarbon/.

controls on new diesel-fueled equipment required by already-promulgated regulations. [37]As EPA indicates, "BC emissions from mobile diesel engines (including on-road, nonroad, locomotive, and commercial marine engines) in the United States are being controlled through two primary mechanisms:

- emissions standards for new engines, including requirements resulting in use of diesel particulate filters (DPFs) in conjunction with ultra low sulfur diesel fuel; and
- retrofit programs for in-use mobile diesel engines, such as EPA's National Clean Diesel Campaign and the SmartWay Transport Partnership Program."

Combustion of biomass in industrial and residential wood combustion also contribute to black carbon emissions in Massachusetts. For industrial sources, available control technologies and strategies include direct particulate matter reduction technologies such as fabric filters (baghouses), electrostatic precipitators (ESPs), and diesel particulate filters (DPFs). Residential black carbon emissions from wood stoves in the Commonwealth have been addressed through rebate offers[38] to assist Massachusetts residents in replacing non-EPA-certified wood stoves with cleaner, more efficient EPA-certified wood or pellet stoves. Wild fires, which contribute substantially to black carbon emissions in many states, are not a significant source in Massachusetts.

Emissions of other SLCPs, such as methane and fluorinated gases, are included in this inventory.

8. Issues for Future GHG Inventories

Technology changes, methodology changes, and data updates will inevitably affect future GHG emissions inventories. Methodologies and data sources are subject to revisions and improvements each year and the Department will continue to use the best data and approaches available. A few potential areas for change include:

Industrial Processes. SGIT bases its calculation of SF_6 emissions from Electric Power and Distribution Systems on the ratio of each state's electricity sales to national electricity sales. SF_6 consumption in Massachusetts and the U.S. has shrunk dramatically since 1990. In Massachusetts, emissions have decreased from 19 to 4 metric tons of SF_6. Beginning with spring 2016, compliance submittals under the new MassDEP regulation 310 CMR 7.72 *Reducing Sulfur Hexafluoride Emissions from Gas-insulated Switchgear* are due, and will be analyzed in comparison to the GHG inventory.

Forest Sequestration and Land Use Change. The value of forested lands as a carbon sequestration sink and the carbon released due to forest land lost annually to land use change were documented in the initial 1990 Baseline. While other land uses also sequester carbon[39], the Department

[37] See http://www3.epa.gov/blackcarbon/mitigation.html.
[38] See the Commonwealth Wood Stove Change-Out program, a partnership between MassCEC, the Massachusetts Department of Environmental Protection and the Department of Energy Resources at http://www.masscec.com/programs/commonwealth-wood-stove-change-out
[39] For example, blue carbon is a form of sequestration that has gained attention in recent years. "Coastal blue carbon is the carbon captured by living coastal and marine organisms and stored in coastal ecosystems. Salt marshes, mangroves, and seagrass beds play two important roles:

focused on forests because those data are most readily available and forests account for the largest portion of naturally sequestered carbon.

While overall forest acreage in Massachusetts expanded greatly from a low point in the mid-1800s (the peak of our agricultural period) to the early 1950s, net forest coverage has begun to decline since then, principally due to the loss of forests to development of land for residential, commercial and industrial uses. At the same time, annual forest carbon sequestration is still increasing as the Commonwealth's relatively young forests mature. The Massachusetts Office of Geographic and Environmental Information (MassGIS) and the University of Massachusetts at Amherst have tracked land use via the interpretation of statewide aerial photography since the 1970s, most recently for photography taken in 2005. To interpolate between available years, and for years since 2005, the Massachusetts Executive Office of Energy and Environmental Affairs has used housing permit data from the US Census Bureau to estimate change in forest cover.

To estimate the net growth of the forest, the Department relied on net growth measured by the United States Department of Agriculture Forest Service at approximately 550 permanent Massachusetts forest plots (known as the Forest Inventory and Analysis (FIA)). The net growth is multiplied by the forest cover acreage to give net growth in tons per county, and converted to tons of CO_2 using a formula derived from chemical analysis of trees (approximately one-half of a tree weight is carbon).

In addition to this aboveground forest carbon storage, a significant amount of carbon can be stored below ground in coarse roots and in forest soils. Organic carbon accumulates in forest soils and can reach density levels nearly equal to that of above ground biomass of a mature forest stand. All exposed soils sequester carbon (at a rate determined by soil class, cover type, and disturbance regime), but only forest soil sequestration is included in Table A2. It should be noted that the inclusion of carbon sinks only from forestry represents a substantial but not complete set of carbon sinks in the state.

As land is developed, trees and vegetation (which sequester carbon) are replaced by buildings, roads, etc. These changes in land use lead to the one-time release of significant quantities of carbon previously locked up in natural ecosystem sinks, as the development disrupts the normal course of the long-term carbon cycle. In order to take account of these emissions, this inventory is using land use change data together with estimates of carbon stored in forests and soil to quantify the annual emissions due to land use change. (Details of land use change and forest sequestration emissions data can be found on the 'Forest & Land Use Change' tab of Appendices C and D.)

EEA is exploring further improvements to the estimation of the benefits of forest protection; such information will be incorporated in future inventories, as available.

- Carbon sequestration—the process of capturing carbon dioxide from the atmosphere, measured as a rate of carbon uptake per year
- Carbon storage—the long-term confinement of carbon in plant materials or sediment, measured as a total weight of carbon stored" http://www.habitat.noaa.gov/coastalbluecarbon.html

Appendix B: MassDEP Emission Reduction Programs for Mobile Sources

February 2015

Program/Activity	Funding	Type of Engines	Status
Alternative Technology			
Diesel Hybrid Truck Purchasing Grant Program MassDEP used funding from the federal American Recovery and Reinvestment Act (ARRA), the federal Diesel Emissions Reduction Act (DERA), and a MassDEP Supplemental Environmental Project (SEP) from an enforcement-related project to offset the incremental cost (up to 25% or $40,000) of purchasing 11 diesel medium- and heavy-duty hybrid trucks for commercial and utility fleets. The hybrid vehicles replaced conventional diesel-powered trucks.	$401,207	Commercial and utility trucks	Completed April 2012
Electrification			
Massachusetts Electric Vehicle Incentive Program (MassEVIP): Fleets Grant Program MassDEP is providing $2.5 million in incentives to Massachusetts public and private entities, including municipalities, state agencies, universities, and drivers' education schools, for the acquisition of electric vehicles and charging stations. Thus far, MassDEP has awarded more than $1.3 million in incentives for 136 electric vehicles and 48 Level 2 dual-head charging stations and is currently accepting applications under Phase 3 of the program.	$2,500,000	On-road passenger vehicles	Active
Massachusetts Port Authority (Massport) Fish Pier Electrification Project For this idle reduction project, MassDEP distributed ARRA funding to Massport to install three Shore Connection Systems to provide electricity for six fishing vessels berthed at the Boston Fish Pier. Boat owners can use the 100-amp system to supply electricity for lighting, heat and other needs. Previously, vessel owners would idle diesel generators 10 to 14 hours a day to supply electricity. Vessels typically dock at the Fish Pier 100 to 300 days a year.	$100,000	Fishing vessels	Completed 2012
Massachusetts Zero Emission Vehicle (ZEV) Action Plan The Massachusetts ZEV Action Plan, which grew out of the *Multi-State ZEV Action Plan* (see below), identifies actions and strategies that are consistent with the multi-state plan and identifies additional state-specific actions that align with the Commonwealth's climate and renewable energy goals, policies, and current ZEV market. The MassEVIP Programs are part of this Plan.	N/A	On-road passenger vehicles	Active
MassCleanDiesel: Clean Markets Program In Round I of this grant program, MassDEP used DERA and SEP funds to replace 52 diesel transportation refrigeration units (TRUs) with electric TRUs that will be connected to the electric grid. The electric units will be installed on privately owned produce trailers serving wholesale markets, distribution facilities, and warehouses. In Round II, MassDEP is replacing 23 diesel TRUs with electric units at fish and produce markets and distribution centers.	Round I: $716,243 Round II: $373,684	Freezer units on produce storage trailers	Round I: Completed May 2013; Round II: Completed September 2015

Program/Activity	Funding	Type of Engines	Status
MassEVIP: Workplace Charging Grant Program MassDEP is providing $1.4 million in funding for the deployment of Level 1 and Level 2 electric vehicle charging stations at workplaces across the Commonwealth. As of December 2014, 153 charging points have been committed to at 87 different street addresses (51 employer/property manager entities) for use by employees.	$1,400,000	On-road passenger vehicles	Active
Multi-State ZEV Action Plan In May 2014, Governors of eight states, including MA, released this Plan to increase the number of ZEVs to a collective target of at least 3.3 million vehicles in the eight states by 2025 and to establish a fueling infrastructure to support the vehicles. The Plan identifies the cooperative actions that each state must undertake to achieve the target; however, each state must take its own steps to achieve its specific goal (see *Massachusetts ZEV Action Plan*, above).	N/A	On-road passenger vehicles	Active
Emission Standards/Limits			
Implementation of California Vehicle Emission Standards MassDEP adopted the California Low Emission Vehicle (LEV) Program for all gas and diesel passenger cars and light trucks sold in Massachusetts. MassDEP also adopted the California LEV Program for heavy-duty trucks with a Gross Vehicle Weight Rating (GVWR) of 8,501-14,000 lbs., which California categorizes as medium-duty vehicles. (For heavy-duty trucks over 14,000 lbs. GVWR, federal standards apply.)	N/A	Diesel light-duty, medium duty vehicles	Active
Ventilation Certification Regulation In 1991 MassDEP established emission limits for ozone precursors and particulate matter for the day-to-day operations of the Central Artery/Third Harbor Tunnel project.	N/A	On-road vehicles	Active
Idling Reduction			
Idling Reduction Toolkits For several years MassDEP used grant funding to distribute idling reduction toolkits to 71 Massachusetts communities and two regional groups working to develop municipal or school-based idling reduction programs. The toolkits contained street signs, hand cards, and guidance materials on how to implement an effective idling reduction program. Although grant funding is no longer available for this project, the toolkit brochures continue to be available on MassDEP’s website.	$54,250	On-road vehicles	Completed December 2009
Massachusetts Idling Regulation and Statute The Massachusetts anti-idling statute and regulation limit idling to five minutes and, except in certain circumstances, apply to all vehicles, including non-road, marine and rail operations, regardless of fuel type. Local boards of health are responsible for enforcing the regulation and statute.	N/A	On-road, locomotive, and off-road engines	Active

Program/Activity	Funding	Type of Engines	Status
Repower/Engine Replacement			
Massachusetts Bay Transportation Authority (MBTA) Locomotive Head-End Power (HEP) Unit Repower Program MassDEP allocated ARRA, DERA, and SEP settlement funds to the MBTA to replace unregulated Tier 0 engines with new Tier 2 compliant (repower) on 18 HEP generator sets in its commuter locomotive fleet. HEP generators supply electrical power used for heating, cooling, and lighting in passenger coaches. Although much smaller than main locomotive engines (670 horsepower versus 3,000 hp), HEP engines typically consume 40 percent or more of the diesel fuel used by a locomotive and emit a substantial amount of the total emissions.	$1,754,766	Locomotives	Completed Dec 2012
Retrofits			
Clean Air Construction Initiative (CACI) (also called the Massachusetts Diesel Retrofit Program) Several large private contractors working for the Central Artery/Tunnel Project installed pollution control equipment on 200 pieces of construction equipment, with equipment costs ranging from $1,000 to $3,000 a vehicle. Diesel oxidation catalysts (DOCs), a type of retrofit technology, were installed in the exhaust systems of bulldozers, excavators, cranes, and other off-road equipment.	N/A	Construction equipment	Completed early 2000s
Diesel Off-Road Engine Retrofit Grant Program MassDEP used a demonstration EPA grant to install DOCs verified for highway engines on 23 municipal construction engines. Twelve municipalities participated in the program and retrofitted equipment included front-end loaders, backhoes, and a 600-horsepower tub grinder.	$50,145	Construction engines	Completed March 2011
Diesel School Bus Retrofit Grant Program Using an EPA grant, MassDEP worked with three vendors to retrofit 46 school buses owned by two private companies, three municipalities and three regional vocational school districts. DOCs or flow-through filters (FTFs), another type of retrofit technology, were installed in the buses' exhaust systems and closed crankcase ventilation (CCVs) systems were installed in the engines. CCVs prevent engine emissions from leaking into a bus's interior.	$119,408	School buses	Completed March 2009
Massachusetts Environmental Policy Act (MEPA) Construction Equipment Retrofit Recommendations Developers of private and public projects meeting certain minimum thresholds for environmental impact must submit their projects for review under the MEPA. MassDEP, which reviews a project's air quality among other impacts, recommends that developers of office projects generating 3,000 or more vehicle trips and commercial projects generating 6,000 or more trips install emission control technology on their diesel construction equipment to reduce emissions.	N/A	Construction engines	Active
MassCleanDiesel: Clean Air for Kids' School Bus Retrofit Program Using state and federal funding provided by the Massachusetts Department of Transportation (MassDOT), the MassCleanDiesel program installed DOCs and CCV systems on 2,114 diesel-powered school buses that serve nearly 310,000 students in 300 communities.	$3,700,000	School buses	Completed June 2011

Program/Activity	Funding	Type of Engines	Status
MassCleanDiesel: Clean Markets Program In Round I of this grant program, MassDEP used DERA and SEP funds to install 23 DOCs and auxiliary power units (APUs) on long-haul trucks serving wholesale markets, distribution facilities, and warehouses. APUs are small, 35-horsepower engines that truckers can switch on during periods of extended idling. There were no applications for APUs and retrofits in Round II.	Round I: $268,911	Long-haul heavy-duty diesel trucks	Round I: Completed June 2013
MassCleanDiesel: State Fleet Retrofit Program MassDEP provided DERA funding to MassDOT to retrofit mostly John Deere Series 544 and 644 wheeled loaders with diesel particulate filters (DPFs) verified by EPA. These vehicles are typically used for on-highway construction projects and/or roadway maintenance. DPFs remove up to 90% of fine particulate matter (PM).	$373,500	Off-road engines	Completed December 2014
Municipal Sustainability Program Grants Through this grant application, MassDEP awarded $20,000 in state grants to six communities in FY 06 to retrofit their municipal on-road and off-road diesel vehicles. Municipalities applied for DOCs or DPFs.	$20,000	On-road and off-road engines	Completed 2007
SEP Project with Aggregate Industries As a result of a SEP with MassDEP, Aggregate Industries-Northeast Region Inc. installed DOCs on 108 concrete trucks—one third of its fleet. The Saugus company operates several quarries in the state.	$125,000	Concrete trucks	Completed 2008
SEP Project with Mirant Canal, LLC As a result of a SEP with MassDEP, Mirant Canal, which operates a power plant in Sandwich, retrofitted 28 school buses owned by the Town of Sandwich with DOCs.	N/A	School buses	Completed December 2007
State Agency Contract Requirements MassDEP requires the MBTA and MassDOT to mandate the installation of emission control technology on the construction engines used in their public works projects.	N/A	Construction Engines	Active
State-Owned On-Road Heavy-Duty Diesel Vehicle Fleet Retrofit Program MassDEP provided ARRA and SEP funding to MassDOT and the Department of Conservation and Recreation (DCR) to retrofit MY 1994 to 2006 dump trucks, plow trucks, rack trucks, truck/crane combination vehicles, and front-end loaders with DOCs.	$699,000	Heavy-duty on-road vehicles	Completed 2010
State Revolving Fund (SRF) Construction Requirements MassDEP requires contractors working on drinking water and wastewater infrastructure construction projects to install exhaust after-treatment technology on construction engines and vehicles with greater than 50 brake horsepower except in certain circumstances.	N/A	Construction engines	Active
Waste Collection Vehicle Retrofit Program MassDEP used ARRA, DERA and SEP funding to retrofit 203 waste collection vehicles with DOCs. Nine private waste haulers and 16 municipalities participated in the three-year program.	$478,876	Waste collection vehicles	Completed March 2012

Program/Activity	**Funding**	**Type of Engines**	**Status**
Vehicle Inspection and Maintenance			
MassDEP Inspection and Maintenance (I/M) Program Under the statewide I/M program, all light-duty vehicles 14 model years old and newer receive an on-board diagnostic (OBD) test, regardless of fuel type, as do model year 2007 and newer medium-duty diesel vehicles and model year 2008 and newer non-diesel vehicles. Any model year 1984 or newer diesel vehicle over 10,000 lbs. GVWR that is not subject to an OBD test receives a tailpipe opacity test (299 vehicles received the test in 2013). In 2013, 12,388 light duty diesel vehicles were inspected. Vehicle inspection tests finance the program.	FY 2013: $13.68 million	On-road vehicles	Active